APPENDIX F

ENVIRONMENTAL IMPACT METHODOLOGY

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This appendix summarizes the methodology used to prepare the environmental impact analyses in this Global Nuclear Energy Partnership (GNEP) Programmatic Environmental Impact Statement (PEIS). A more detailed discussion of the methodology for certain impact analyses is contained in separate appendices, specifically Intentional Destructive Acts (Appendix B), Human Health and Worker Safety (Appendix C), Facility Accident Scenarios (Appendix D), and Transportation (Appendix E). The methodology used for the Domestic Programmatic Alternatives analysis is provided in Section F.1, and that used for the International Activities analysis is provided in Section F.2.

F.1 ENVIRONMENTAL IMPACT METHODOLOGY FOR THE DOMESTIC PROGRAMMATIC ALTERNATIVES ANALYSIS

This GNEP PEIS analyzes the potential environmental impacts associated with the current United States (U.S.) commercial nuclear fuel cycle and broad implementation of alternative nuclear fuel cycles. As a result, the analysis is necessarily broad and long-term, focusing on the potential impacts that could result from implementing each of the programmatic alternatives over many decades.

As described in Chapter 2, six domestic programmatic alternatives are analyzed in this PEIS:

- No Action Alternative—Continue Existing Once-Through Uranium Fuel Cycle
- Fast Reactor Recycle Alternative
- Thermal/Fast Reactor Recycle Alternative
- Thermal Reactor Recycle Fuel Cycle Alternative
- Once-Through Fuel Cycle Alternative Using Thorium
- Once-Through Fuel Cycle Alternative Using Heavy Water Reactors (HWRs) or High Temperature Gas-cooled Reactors (HTGRs)

F.1.1 Electricity Projections, Nuclear Share of the Electricity Market, and Planning Period

This PEIS analyzes broad implementation of each programmatic alternative in terms of total nuclear generating capacity. Data from the Energy Information Administration were used to determine electricity growth projections. Each year, the Energy Information Administration publishes the *Annual Energy Outlook*, which provides projections and analysis of domestic energy consumption, supply, prices, and carbon emissions, among other factors. The most recent version of the *Annual Energy Outlook* (the 2008 Release) provides such projections through 2030 (EIA 2008a). The Energy Information Administration's estimates assume the continuation of known trends in demographics and technology improvements and also assume that no changes occur in current laws, regulations, and policies. Assumptions regarding future electricity demand and nuclear power's share of the market affect estimates of the potential quantities of spent nuclear fuel (SNF) that would be generated and require management. The amount of SNF is an important parameter as it drives, among other factors, the amount of transportation, the potential capacity of future recycling facilities, the requirements for future geologic repository capacity, and other radioactive waste disposal capacity.

In this PEIS, the U.S. Department of Energy (DOE) assesses programmatic alternatives that would support an increase in nuclear electricity production. While DOE acknowledges that market forces (i.e., economics) would likely be the biggest factor influencing future nuclear electricity production, market forces are beyond the scope of this PEIS. This PEIS assumes that factors beyond the scope of this PEIS would not be barriers to the widespread implementation of any reasonable domestic programmatic alternatives. Further, DOE recognizes that a commitment by DOE to one or more of the programmatic alternatives could impact how the market views the economics of nuclear power.

Because of uncertainty with respect to the rate of growth in nuclear generating capacity, the GNEP PEIS considers a range of growth rates: zero growth, 0.7 percent annual growth, 1.3 percent annual growth, and 2.5 percent annual growth.[1]

To allow time for broad implementation of the alternatives, the projections for nuclear-generated electricity growth were extended through approximately 2060 to 2070. Based on the growth rates set forth above, all of the PEIS alternatives were assessed at capacities of 100 gigawatts electric (GWe) (zero growth), 150 GWe (0.7 percent annual growth), 200 GWe (1.3 percent annual growth), and 400 GWe (2.5 percent annual growth). Each alternative was analyzed to determine what facilities and capacities would be necessary to achieve these generating capacities. Certain decisions could have significant environmental impacts well beyond 50 years, particularly in terms of impact on the capacity requirements for future geologic disposal. To the extent practical, this PEIS considers these impacts, typically in a qualitative manner.

F.1.2 Facilities and Capacities Needed to Meet the Demand and Data Quality

For each programmatic alternative, DOE determined the facilities, capacities, infrastructure, and other activities that would be needed to meet its assumed demand discussed in Section F.1.1. Once facilities were identified, DOE used the best available data to define the resource requirements and potential environmental impacts of construction and operation of the facilities and activities. These data were generally pre-conceptual information developed specifically for this PEIS or existing data developed for similar facilities. The quantity and quality of data concerning each alternative varies. Some facilities (such as SNF storage facilities) are operational and have actual data available; other facilities (such as a nuclear fuel recycling center that uses the UREX process to separate SNF into usable products and waste and makes transmutation fuel from the usable constituents) have never been operated on a commercial scale. Some data were obtained from sources within the United States, while other data were obtained from foreign sources, including the International Atomic Energy Agency (IAEA) and the Korean Atomic Energy Research Institute. For example, much of the information for the

[1] The 0.7 percent and 1.3 percent annual growth rates are based on Energy Information Administration estimates for nuclear generating capacity and total electricity demand as of December 2007 (EIA 2007a). As this draft PEIS was being prepared for issuance, the Energy Information Administration revised these estimates to 0.6 percent and 1.1 percent, respectively (EIA 2008a). DOE will address these, and any newer Energy Information Administration estimates, in the final PEIS, as appropriate.

DUPIC[2] fuel cycle was obtained from Korean and Canadian resources. In all cases, DOE used judgments of engineers and researchers to identify and utilize the best data available.

DOE used these data to estimate the amount of land required for the various potential facilities, the types and quantities of wastes that would be generated, the number of employees that would be required for construction and operation, the amount of water the facilities would use, and other resource requirements. DOE then used this information to estimate environmental impacts. The PEIS analysis focuses on the annual resource requirements for nuclear power reactors (e.g., uranium and/or thorium), the amount of waste that would be generated and need to be disposed, the amount of uranium and other actinides that could be recycled, human health and accident impacts, and the impacts of radiological materials transportation.

F.1.3 Facility Locations

For certain PEIS analyses (e.g., impacts to human health from normal operations and accidents), DOE defined the characteristics of six generic sites to assess the potential impacts associated with the facilities under the domestic programmatic alternatives. These sites provide a range of values for two parameters—offsite (50 miles [mi] [80 kilometers {km}]) population and meteorological conditions—that would directly affect the offsite impacts. Appendix D provides more details on these generic sites.

All of the GNEP programmatic alternatives, including the No Action Alternative, would produce materials (e.g., either SNF, high-level waste [HLW], or both) that would need to be isolated in a deep geologic repository as a means of final disposition. The PEIS analyzes the generic impacts of siting, constructing, and operating future geologic repository capacity and the impacts associated with transporting these materials to a geologic repository (see Section F.1.5). Some of the closed fuel cycle alternatives could also separate cesium (Cs) and strontium (Sr) wastes that would require transportation to a storage or disposal facility or be stored onsite. The PEIS assesses both of these alternative scenarios. Additionally, this PEIS assesses the impacts of storage and transportation associated with other radioactive wastes (e.g., low-level waste [LLW] and Greater-than-Class-C [GTCC] LLW). Transportation of these wastes to future disposal facilities is analyzed.

F.1.4 Resource Analyses

In general, the PEIS analyses were tailored to the decisions to be made following completion of the PEIS. Consequently, the PEIS presents the "types of impacts" that could result, while acknowledging that the specific impacts could be site dependent. For example, the PEIS indicates the amount of water that a facility might require but does not estimate what the impacts of using this much water would be, as that would be a function of the facility location. A facility that requires 1 billion gallons (3.8 million m^3) of water annually might have small impacts at a site where a large volume of water is readily available. Also, actual water requirements could vary based on future design considerations (e.g., related to cooling systems).

[2] DUPIC = direct use of spent pressurized water reactor (PWR) fuel in CANDU.

A screen of all relevant resources was conducted to identify those potential impacts that could be meaningfully evaluated at a programmatic level. For several resource areas, DOE decided that a meaningful programmatic analysis was not possible, particularly in the absence of site-specific information. For example, impacts to cultural and paleontological resources were not analyzed at the programmatic level because impacts would be inherently site-specific and a programmatic assessment would not provide meaningful data for the decision maker. Other resource areas similarly screened from this programmatic analysis are biological resources, environmental justice, geology and soils, noise, and site infrastructure. Chapter 4 of this PEIS includes a discussion of the following resource areas:

Land Resources: Impacts to land would be site dependent. As such, impacts were assessed based on the amount of land that would be associated with implementation of each alternative.

Visual Resources: Impacts to visual resources would be site dependent. As such, impacts were assessed by determining whether any impacts, beyond the facilities themselves, would affect visual resources at relatively large distances. For example, if a facility generated a visible water vapor plume from cooling tower operations, this would be identified.

Water Resources: Impacts to water resources would be site dependent. The PEIS presents the amounts of water that could be required for facilities.

Air Resources: Impacts to nonradiological air quality would be site dependent. The PEIS provides qualitative discussions of potential impacts to nonradiological air quality. Radiological impacts associated with air emissions are discussed below under "Human Health (Normal Operations)."

Socioeconomic Impacts: Impacts to socioeconomics would be site dependent and would occur primarily in communities in the vicinity of any future facility. The PEIS provides estimates of the number of workers required for both construction and operation.

Human Health (Normal Operations): Impacts related to health and safety would be both site dependent and site independent. For example, impacts to workers at a facility would occur regardless of the location. DOE estimated the impacts to workers and presented them in terms of potential latent cancer fatalities (LCFs) from radiological exposures during normal operations. Estimates of potential impacts were based on data for existing facilities (e.g., worker exposure data from existing reactor operations) or pre-conceptual data developed for proposed facilities (e.g., for a nuclear fuel recycling center, worker exposure data were specifically developed). For differing reactor technologies, the PEIS assumed that worker doses would not be significantly different than the average doses to workers at existing light water reactors (LWRs); no data were discovered that invalidated this assumption.

With respect to potential impacts to the public, exposures would vary depending on many factors, including radiological releases from facilities, prevailing weather patterns, and the proximity of the facilities to local population centers. The availability of data to estimate impacts to the public varied among the alternatives. Based on modeling results for generic sites, the impacts (in terms of dose and LCFs to the maximally exposed individual and the surrounding 50 mi [80 km] population) from normal operations are presented.

For some alternatives, specific radiological release data were not available. In these instances, DOE estimated public exposures based on compliance with expected licensing regulations. For example, any new commercial nuclear facility would be required to comply with the U.S. Nuclear Regulatory Commission (NRC) regulations. Title 10 *Code of Federal Regulations* (CFR) Part 20 (10 CFR Part 20) requires that each licensee conduct operations so that the total effective dose equivalent to individual members of the public from the licensed operations does not exceed 100 millirem (mrem) in a year. Furthermore, 10 CFR Part 20 requires that power reactor licensees comply with the U.S. Environmental Protection Agency's (EPA's) environmental radiation standards contained in 40 CFR Part 190 (i.e., 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ of any member of the public from the uranium fuel cycle).

Accidents: Accident impacts would also be dependent on many factors, including the types of accidents, radionuclides released, site characteristics, and the distribution of population in the surrounding environment. Appendix D explains the methodology that was employed to estimate the impacts for a range of accidents at six generic sites for the various facilities analyzed in the PEIS. These accident analyses are representative of the types of accident impacts that could result from these facilities. The PEIS presents a range of impacts associated with accidents (e.g., impacts from both high probability/low consequence accidents and low probability/high consequence accidents).

Intentional Destructive Acts: In addition to the accident analysis, DOE prepared an impact analysis of terrorist acts, Appendix B.

SNF and Wastes: Impacts from wastes and SNF were analyzed based on estimates of the amount of material that would be generated for each of the four analyzed growth rates during a period of approximately 50 to 60 years and of annual generation at the four analyzed nuclear generating capacities identified above. SNF and wastes would be managed in accordance with regulatory requirements. For SNF and some wastes, such as HLW, this PEIS analyzes impacts associated with the transportation of these materials to a geologic repository (see Section F.1.5).

As mentioned in Section F.1.3, Cs and Sr, if separated from LWR SNF, could be transported to a storage or disposal facility or stored at a recycling facility for extended time frames up to approximately 10 "half-lives"[3] following recycle (approximately 300 years). If stored at the recycling facility, institutional controls to safeguard this material would be required during this time period. The PEIS assesses these alternative scenarios.

All of the alternatives would generate GTCC LLW, either during normal operations or during decontamination and decommissioning. The *Low Level Radioactive Waste Policy Amendments Act* of 1985 assigns the responsibility for the disposal of GTCC LLW to the Federal Government (DOE) (42 U.S.C. 2021). This legislation specified that the GTCC LLW must be disposed in a

[3] Radioactive materials decay over time. "Half-life" refers to the time required for the quantity of a radioactive material to decay to half of its initial value. After approximately 10 half-lives, there would be approximately a 99.9 percent reduction (or a factor of 1,000 reduction) in the amount of the isotope present.

facility licensed by the NRC. There are no facilities currently licensed by NRC for disposal of GTCC LLW. This PEIS assesses the transportation impacts of GTCC LLW to a hypothetical disposal site using a range of distances to account for the unknown origin and destination of this material.

Resource Requirements: DOE analyzed the resources that would be needed to support the programmatic alternatives. For example, this PEIS assesses the amount of uranium and thorium (as appropriate) that each alternative would require and discusses the availability of that resource.

Sensitivity Analyses: This PEIS includes sensitivity analyses, as appropriate, for each alternative. For example, for the Fast Reactor Recycle Alternative and the Thermal/Fast Reactor Recycle Alternative, the ultimate deployment of fast reactors could be affected by the conversion ratio (CR)[4] of fast reactors. Because the CR is essentially a measure of the efficiency by which a fast reactor consumes transuranics, it could directly affect how many fast reactors would be deployed, the percentage of transuranics that would be consumed, and how much SNF and HLW would require disposal in a geologic repository. This PEIS assesses how the impacts presented could change depending on changes in the CR. Other sensitivity analyses include a discussion of differing SNF separation technologies and the use of differing mixed-oxide reactor fuels.

F.1.5 Impacts of Transportation

A transportation analysis was prepared to determine the potential impacts associated with transporting all radiological materials (i.e., fuels and waste) associated with the domestic programmatic alternatives. The transportation analysis determined the number of radiological shipments (i.e., for both rail and truck, broken down by material to be transported) that would be required for each alternative.

The routes were analyzed using the routing computer code WebTRAGIS (Johnson and Michelhaugh 2003). The routes were calculated using current routing practices and applicable routing regulations and guidelines. Route characteristics include total shipment distance between each origin and destination and the fractions of travel in rural, suburban, and urban population density zones. Population densities were determined using data from the 2000 census.

The PEIS considered route characteristics for truck and rail transport over distances of 150, 500, 1,500, 2,100, and 3,000 mi (241, 805, 2,414, 3,380, and 4,828 km). Of the values provided above, shipments analyzed at the 2,100 mi (3,380 km) distance are used as the representative case for the domestic programmatic alternatives analyses. The population density values for all five scenarios were updated to reflect census 2000 data. Appendix E provides additional details regarding the methodology that was used to perform the transportation analysis.

[4] As used in this PEIS, the "conversion ratio" (CR) of a fast reactor is the ratio of the amount of transuranic elements produced to the amount that is consumed in the reactor during the time the fuel is in the reactor. The CR determines the number of fast reactors required to consume transuranics separated from the LWR SNF. At a CR of 0.5, approximately 20 percent of the transuranics would be destroyed per fast reactor recycle pass. The PEIS also includes a sensitivity analysis of changing the CR.

Transportation impacts are presented in terms of radiological impacts (expressed in person-rem and converted to LCFs using a dose-to-risk conversion factor of 600 fatal cancers per 10^6 person-rem, which equates to 6×10^{-4} LCFs per person-rem [DOE 2002h]). The results of the transportation analysis are presented in two sets of tables for each alternative. The first set of tables presents the impacts associated with handling (loading and inspection). The impacts of handling are independent of the distance that the material would be transported. As such, the handling impacts would be the same whether the SNF is transported, for example, 500 mi (805 km), 2,100 mi (3,380 km), or any other distance. For this reason, these impacts were presented separately from the in-transit impacts (which are presented in the second set of tables).

Unlike handling impacts, the in-transit impacts are dependent on the distance that material would be transported. The locations of future facilities (e.g., reactors, nuclear fuel recycling centers, and a geologic repository) are unknown. The in-transit impacts for the transportation of SNF or HLW to a geologic repository are based on 2,100 mi (3,380 km) of transport. This distance was selected because it is the average distance that has been analyzed previously (in *National Environmental Policy Act* [NEPA] documents) for all SNF and HLW considered for geologic disposal. The in-transit impacts would vary based on a variety of factors, including the distance that the radiological materials would be transported, the specific routes that would be utilized, the population densities along those routes, and others. Of these factors, the transport distance is considered to be the most significant factor. This PEIS analyzes how the impacts would change as a function of distance traveled. Although the in-transit impacts are not exactly "linear" (i.e., twice the impacts for twice the distance transported), it is a close approximation. Consequently, if the radiological materials were transported 500 mi (805 km), all of the in-transit impacts could be calculated by multiplying the values in those tables by 0.24 (500/2,100). Appendix E provides additional information regarding the assumptions, methodology, and impacts for the transportation analysis for the programmatic alternatives.

F.1.6 Common Impacts

DOE identified actions and impacts that would be common to all of the domestic programmatic alternatives. Such things as uranium mining, uranium enrichment, uranium fuel fabrication, and continuation of the Advanced Fuel Cycle Initiative (AFCI) fit into this category. Although the associated impacts would be common, this does not mean impacts would be exactly the same for each alternative. For example, although each alternative would require uranium enrichment, both the quantities of uranium requiring enrichment and the percentage of enrichment could be different. Those differences, where notable, are discussed in the PEIS. DOE used the best available information to estimate these impacts, including existing NEPA documentation. For example, for uranium enrichment, DOE used a recent (2006) EIS prepared by the NRC to estimate the types of impacts that would result from uranium enrichment (NRC 2006b).

F.1.7 Cumulative Impacts

A cumulative impact analysis was prepared for the domestic programmatic alternatives. The methodology for that analysis is described in Chapter 5.

F.2 Environmental Impact Methodology for the International Activities Analysis

Impacts associated with international activities related to GNEP are discussed in Chapter 7, which includes a qualitative analysis of transportation in the United States and across the world's oceans, as well as other types of potential impacts. The methodology used for this analysis is described in Chapter 7, Section 7.2.

F.3 REFERENCES

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40 CFR Part 190 — Environmental Protection Agency (EPA), "Environmental Radiation Protection Standards for Nuclear Power Operations," *Code of Federal Regulations,* Office of the Federal Register, National Archives and Records Administration, Washington, DC, Revised July 1, 2007.

42 U.S.C. 2021 — "Low Level Radioactive Waste Policy Act, Amended," LLRWPA, *United States Code,* Washington, DC, January 15, 1986.

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